

Heat Release in Freely-Propagating Lean Premixed Hydrogen-Methane Mixtures

Xinfeng Gao

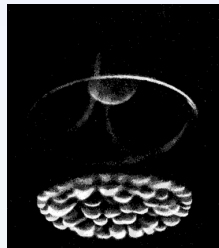
Center for Computational Sciences and Engineering
Computational Research Division
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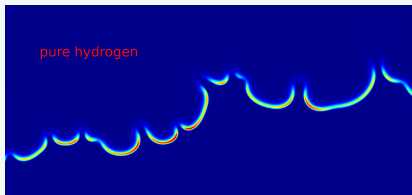


Objective

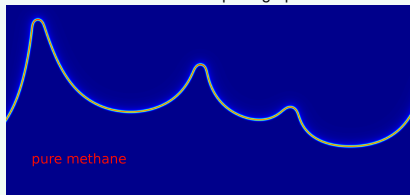
- Investigate addition of methane to hydrogen to reduce thermodiffusive instability
 - Transition from cellular burning to Landau-Darrieus instability only



photograph taken in 1959



$$\phi_{H_2} = 0.37$$

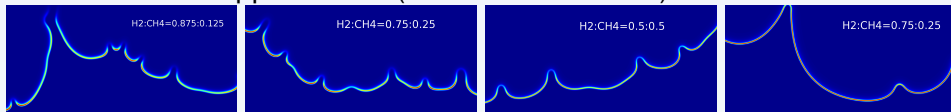


$$\phi_{CH_4} = 0.7$$

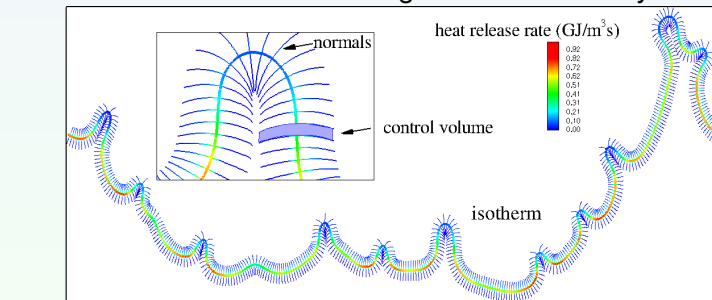
Flame Images of Hydrogen-Methane Flames

Simulated with adaptive low Mach number combustion algorithm¹ using 21 species and 84 reactions

A. Flame appearances (field of heat release)



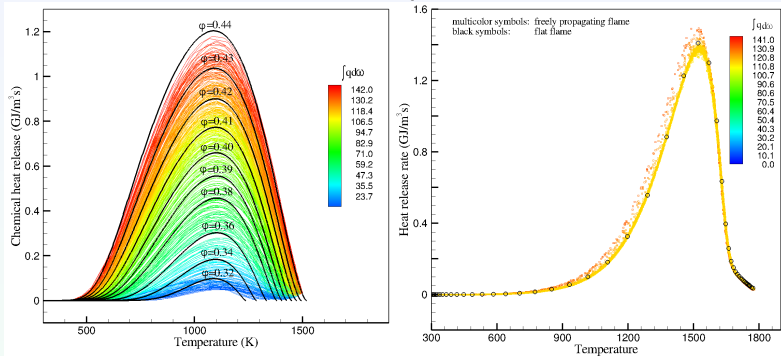
B. Local “flame”-based orthogonal coordinate system



¹ M. S. Day and J. B. Bell, “Numerical Simulation of Laminar Reacting Flows with Complex Chemistry”, Combust. Theory Modelling 4(4) pp.535-556, 2000

Heat release structure

C. Heat release structures of lean pure H_2 and CH_4 flames

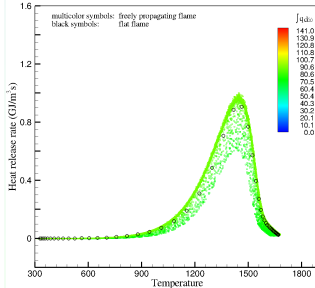
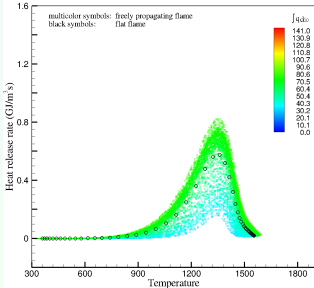
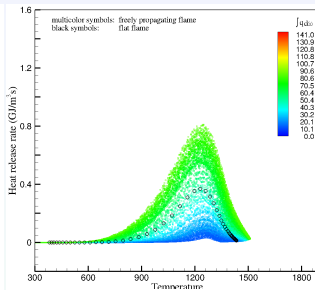
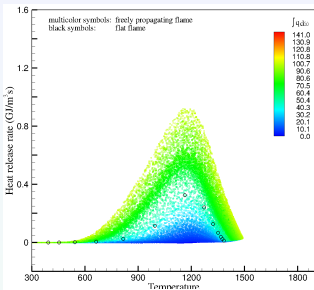


- 1 Freely propagating H_2 flame can be viewed as many flamelets with different equivalence ratios²
- 2 Freely-propagating CH_4 flame shows little variability with curvature

²X. Gao, M. S. Day and J. B. Bell, "Characterization of Freely Propagating Hydrogen Flames", Fall Technical Meeting of the Western States Section of the Combustion Institute, Irvine, Oct. 2009

Heat release structure

D. Heat release structures of lean H_2 - CH_4 mixed flames



1. extinction events (along “flame” surface) disappear as increasing CH_4
2. weakly burning regions have essentially 1-D structure as increasing (more) CH_4
3. $\frac{\dot{Q}_{\text{peak, freely propagating}}}{\dot{Q}_{\text{peak, flat}}} \rightarrow 1$ as increasing f_{CH_4}

Local Burning Speeds and Curvature Effects

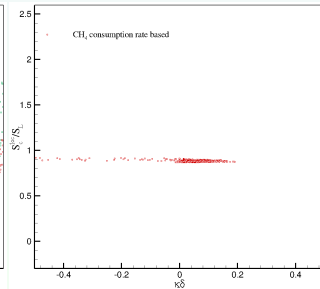
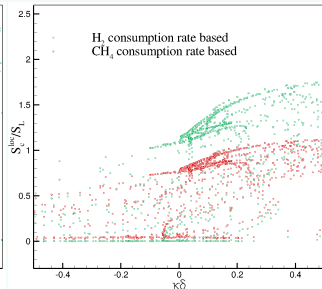
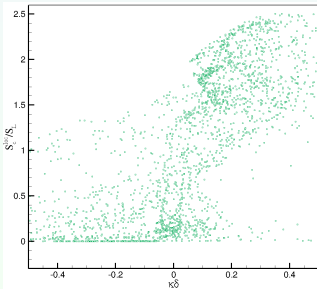
F. Behavior of local burning speeds

1 Definitions

$$S_c^{loc,f} = \frac{1}{A(\rho Y_f)_{in}} \int_{\Omega_k} \rho \omega_f d\Omega_k \quad \frac{S_c^{loc,f}}{S_L} = 1 - M_a^f f(\kappa\delta), f = \text{H}_2, \text{CH}_4$$

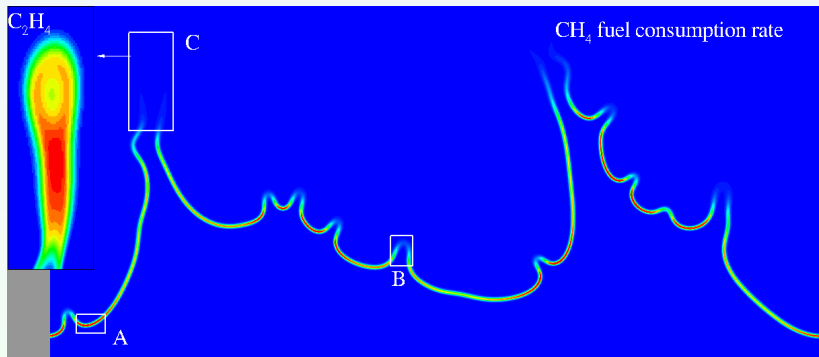
2 Observations

- Positive slope reflecting a negative Markstein number
- Increase in the $M_a^{\text{CH}_4}$ along with an increase in f_{H_2}
- Extinction of CH_4 at negative curvature in $\text{H}_2/\text{CH}_4 = 0.875:0.125$



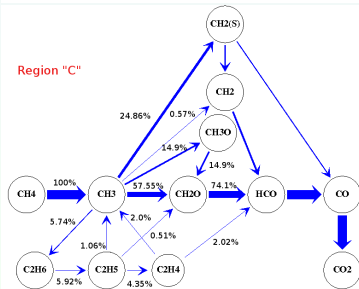
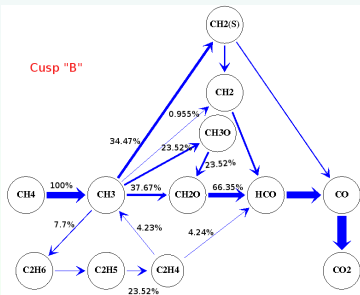
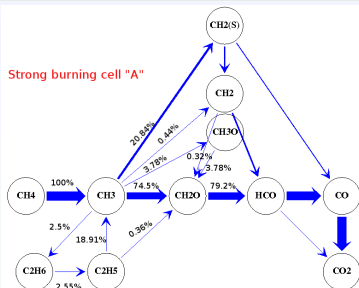
Hydrogen-Methane Flame: $\text{H}_2:\text{CH}_4 = 0.875:0.125$

- E. Reaction pathways of Carbon chemistry of a quasi-steady premixed H_2/CH_4 (0.875:0.125) flame in regions: strong burning cell (A), cusps (B), and a flame folding region (C)



Reaction Pathways of Carbon Chemistry

- 1 similar pathways overall
- 2 shifts in C/C₂ pathways
- 3 Different extinction mechanisms in "B" & "C"



Concluding Remarks:

- Heat release structures seem to follow a single parameter family curves of 1D flames for hydrogen-methane flames
- These observations will allow us to develop reduced models describing hydrogen-methane flame propagation

Related Ongoing Work:

- How the turbulent diffusion/transport (heat and mass) process competes with their molecular counterparts